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Enhancing the Value of Early Stage Prototyping in Product Development

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Abstract : Any product development is riddled with obstacles. Establishing a process enables tackling these problems in a systematic manner. The contemporary development process is Dynamic and multidisciplinary. Use of prototypes since very early on in the process can potentially Make the process more dynamic and effective. Prototypes help in verification and refining the idea. A prototype can also be a very effective communication media between the various stakeholders. To get the full benefit of prototypes it is necessary to define what prototype is. Any physical representation of idea from a simple sketch to pre-production versions can be considered to be a prototype. The early stage prototypes, the low resolution and mock-ups can prove to be the most helpful if used correctly. The prototypes can be in the realms of technology, engineering and Human aspects, which come under design.

To assess the effect of prototyping an experiment in form of PD6 workshop was conducted. The Experiment was inconclusive, the reasons for that have been discussed.

With the right knowledge and techniques using prototypes since the very beginning can make the Development process efficient and effect and reduce the chance of failure

Keywords Product Development, Prototyping, Early stages, Value

Acknowledgement

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To make anything better it's necessary to eliminate the faults and drawbacks. I thanks Anniina, Karri and Pushkar for being the critics who outlined the flaws so that my work gets better.

Finally a big thanks to all those who stood by when things got tough

Saurabh Ingale Espoo

02.25.2016

Contents

1. Introduction

1.1. Background

Developing new technologies and products is very unique to mankind and has put us on a path to rapid developments in new ways to solve problems and find solutions to our needs. During my studies at Aalto University I had the opportunity to participate in the Product development Project course better known as PDP held at Aalto Design Factory in 2013-14 which fascinated me and got me interested in understanding the process in closeness.. During the course, student teams are given an industrial project, which they work for the academic year and present their solutions in the end gala. The industry partner sponsors the project and the teams have a budget of € 10,000. The student teams are multidisciplinary such that each team has at least one student from faculty of Engineering, Design and Business. Working in multidisciplinary teams on real industrial problems gave a better perspective on the behind the screen processes of product development. The importance of interaction between the different disciplines and their inter dependencies was the single biggest learning. Difference in perspectives to the same issue highlights the need for subsequent communication to make collective team decisions. Having the right information while making decisions instead of just collective knowledge to do the job at hand is a determining factor in success of the project is

In 2014-15 I participated in the Challenge Based Innovation Course in association with CERN. The course focuses on finding practical application for technologies developed at CERN. As in PDP course, the teaching team encouraged us to start prototyping early on and start with quick and dirty ones. Even though it was easy to build things from paper and cardboard it was difficult to understand how to use them for the project as they are not

intuitive in the overall academic process. After learning the techniques and logic behind these kinds of prototypes, it proved to be extremely valuable for the projects. This inspired me to look into the overall functioning of prototypes, concentrating on early stages, as they are what predominantly determine the success of the project and help in making better products.

1.2. Objectives

This thesis focuses on a simple objective – "How to make the prototyping effort in the early stage of the project more effective and productive?" A lot of my fellow students including myself, in the product development course were a bit lost with early stage prototypes and prototyping processes. These prototypes were easy to build and at times incredible fun too, however their purpose was a bit unclear and lost. Even though the teaching team encouraged testing the early prototypes or as at times it was a deliverable as part of coursework, we found it difficult to make sense on how to proceed and to use data generated in the this testing.

The objective of this thesis is to come up with a handbook to guide through the early stage of prototyping to make it much more useful to the product development process. The handbook should lay out some basic guidelines on how to build quick prototypes focusing more on the logic and the thought process behind them rather than the techniques. Testing of the prototypes generates the real value for making them and hence the handbook should also provide guidelines for testing and more importantly analysing the test results.

It is not expected from the handbook to answer all the problems relating to the early stage prototypes but it should serve more as guidelines to make the process more productive. The thesis attempts to remove the perception that quick and dirty prototype is complex and difficult phase. It actually acknowledges that it's simple, incredibly useful and fun way to advance the project. The handbook should encourage all product developers to include a more prototype intensive processes as a way of working. The pedagogical aspect of using prototypes it is out of scope.

1.3. Structure

This thesis can be split in two broad sections. The first section is more academic in nature. It delves into the research that goes in the academic world and its verification in the controlled settings of an experiment. The second section is more practical oriented - the what and the why of prototyping in the dynamic environs of product development.

Product development has been proposed to be a very systematic and a sequential process especially from an engineering point of view. The study material used in the product development course at ADF was used for this purpose. Processes described in study materials are the ideal case scenarios of product development . Apart from the course material, published research articles related to the role and effect of prototypes on early phases of product development were studied. Most of the studies have been conducted in an academic setting with control over the variables. They lack the uncertainty and constraints imposed in practical setting of product development.

.The aim of thesis is to make the work more applicable in practical domain rather than academic one. Towards this purpose, more emphasis is given to gathering information, tips and guidelines from the practitioners. The community of Design Factory has been extremely useful in this aspect. Having access to people with vast experience in the field of prototyping both in industrial setting as well as the academic projects at ADF was extremely useful in getting insights to all aspects of prototyping . The collective experience over a variety of projects over the years is hard to replicate.

It is always useful in subjects of practical practice to have some cases studies. Two hardware start-ups based in ADF provided the required practical examples of things to be done with development process they followed. LeeLuu labs with their touch sensitive fabrics and Trick technologies makers of throw able microphone Catchbox are the case studies included in this

thesis. The experiences and insights of the practitioners are complementary to the findings of the academic research. Both the sources have been used in parallel to form the guidelines

A workshop experiment was also conducted to study effects of early stage prototyping. It was a variation of PD6 used to kick-start the PdP projects. The very nature of the workshop and its outcome made it difficult to asses the impact of prototypes. However the workshop did highlight the need for such guidelines.

The thesis ends with discussion about all the information and insights gained during the process. Some experiences in this field acquired by being part of this way of working at ADF have also been included in the thesis.

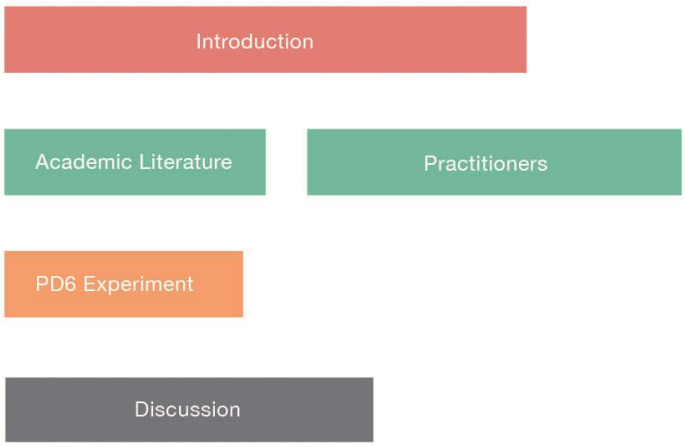


Figure 1

Flow and structure of thesis

2. Product Development process

2.1. Why to follow a process

Any new product is the result of a characteristic evolutionary process which develops an idea into its end manifestation as the product. A process can be defined as sequential series of events which are aimed at achieving a predefined goal within the stated constraints. For product development these aim at conceptualizing, designing and commercialising a product successfully

A process has well defined phases and checkpoints to pass. A good process has wisely chosen checkpoints in transition between the different phases of development. The checkpoints are the parameters and standards that the product is supposed meet. This helps in reducing the risk of failure in the later stages of development by assuring quality of work. Product development process is a cross-domain and quite often multidisciplinary process with various stakeholders. A well organized process co-ordinates all the players onto to a common understanding necessary for smooth functioning and delivery of the individual tasks to merge seamlessly into a product. A process is based on milestones to be passed at specific intervals which sort of act as an overall schedule and plan for the project. This planning is necessary to track the progress and ensure timely completion of the project. The output of planning also creates a management structure critical to achieving the goal in set constraints. A process always entails documentation of the events that occur, which on analysis can identify any opportunities for improvement to the product or the process itself [17] [21].

2.2. What is the process

A process can be considered as a knowledge and information processing system. The information regarding the user needs, existing technologies, organisational strategies and commercial aim are processed to deliver a product that meets the pre set goals. It achieves this by creating a wide range of evolving concepts which are narrowed down to be iterated upon, until it can be produced reliably and repeatedly by the production setup. It also works as risk management system. It works by identifying the risk early on and then eliminating the potential uncertainties by validating the functions. The whole philosophy should be to use the process checkpoints to fail early and fail fast in the benefit of saving precious resources and time.

The discussed process here is a generic version of product development. It changes depending on the kind of product being developed, the constraints under which it is developed and also the organisational structure and philosophy of the enterprise undertaking the development.

Process begins with Planning of the whole process. This is the zero mark, as it precedes the approval and initiation of the project. Focus during this phase is on opportunity identification and researching the existing technology. The output or the phase conclusion is the detailed project statement covering the opportunity, business aims, technology feasibility and available resources with all the assumptions and constraints stated clearly. The actual development of the product begins with Concept Development. After identifying the opportunities and needs of the target market/user, multiple concepts satisfying the same are generated. A concept describes the form, function and features of product along with rough specification of the same. After analysing the different concepts the best ones that suit the project requirements are chosen for further refinement and detail development.

The concept is refined in the next stage, which deals with System Design. This phase defines the product architecture with the product subsystems and comprising components. Result of the system levels is the geometric layout which is necessary to start planning of the production process layout. At this point the detailed functional requirements and features are finalised. Any product to function as intended needs all the details to be sorted out.

System design is followed up by figuring out the small details that make-up the product in phase of Detail Design. The complete specification of geometry, materials of all the components and how they are sources is chalked out. It also fixes the tooling and the manufacturing process plan for the whole product. The most critical aspects of the project plan namely materials, production cost and the performance parameters are fixed by the end of this phase .

Testing and Refinement phase consists of constructing multiple pre production versions and testing them to find out faults and verify the design decisions. Normally this process consists of two main types of prototypes. Alpha prototypes are made to the final geometry and with the actual material but the production methodologies are not the ones to be used for the mass production. These are basically made to verify the design and find out to what degree does the product satisfy the needs it's made for. These are followed by Beta. These are prototypes made from actual production techniques, these are almost the final products made to find out any faults or shortcoming in the product or production process. They are at times tested with actual customers in their own environment. This results in reliably performing products satisfying the design challenges [21].

The above discussed is the traditional development process, A linear process predominantly engineering oriented. In PDP and other product development courses at ADF the process followed is quite different. Its a dynamic process which is based on continuous loop of build test analyse[4]. The process also suggests the user to be involved from the very early stages

rather than just testing the final versions. The user is involved throughout the process in different capacities, from problem identification to testing even the earliest of the prototypes. This process is more about engaging the end user in co-creation rather than creating for the end user. Most of the decisions relating to the product are based on prototypes and testing them rather than collective knowledge of the team. Use of rough, very basic prototypes helps in clarifying and verifying the idea and the features early on puts the development process on the right track making it much more resource efficient and reducing the risk of failure. This process enhances understanding of the problem at hand and since all the decisions are based on validated idea results in a better solution. This is also aided by enhanced communication with prototypes acting as interactive facilitator for the whole process. The iterative process can be expressed in a very systematic manner but is very instinctive and flexible in practice.

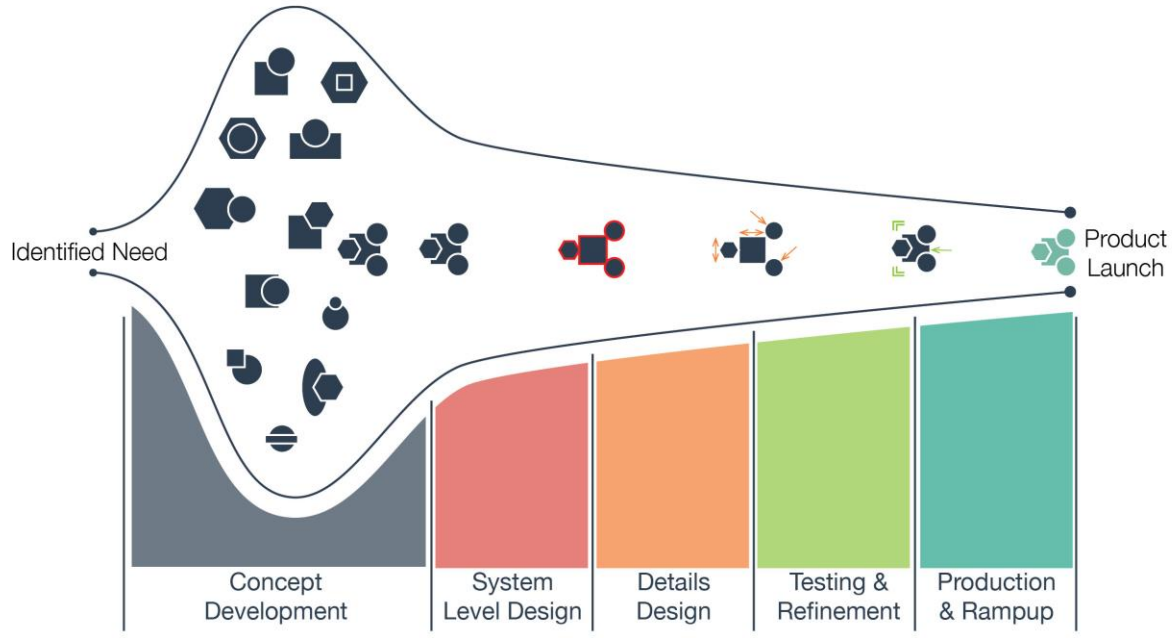


Figure 2.1

Traditional product Development process

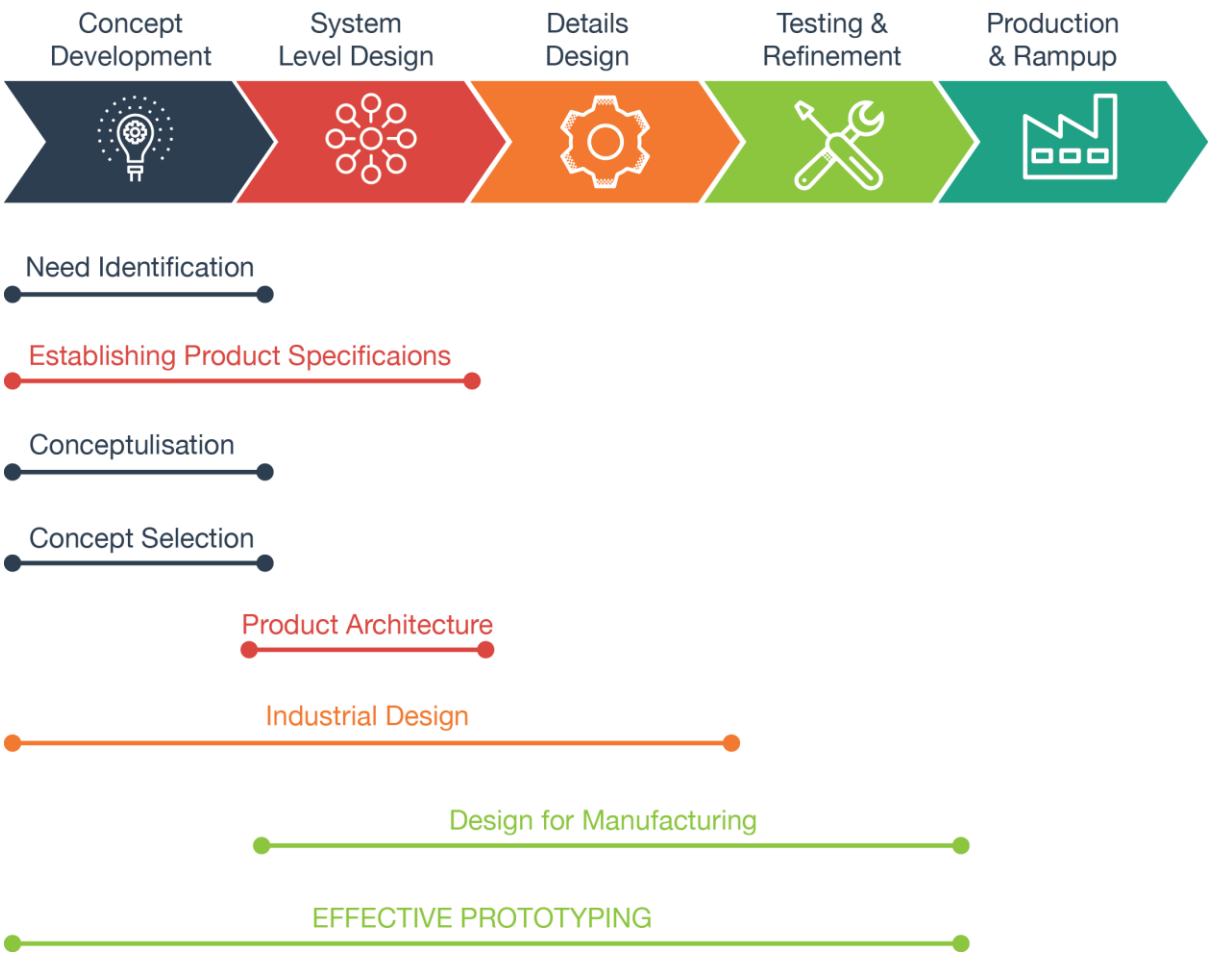


Figure 2.2 The outcome of each stage and the means used in the stage

The traditional product development process is described to be linear but due to the overlap of different phases and disciplines it becomes a loop and tangled

3. Prototype

3.1. What is a prototype?

During the many stages involved in the journey from an idea to an end product, details and improvements get added at every stage. A physical, tangible outcome built at the end of each refinement stage to the test the assumptions and viability of the approach is called as a prototype. In the conventional process only the end pre production versions the 'Alpha' and 'Beta' stages were considered to be prototypes. [21] But with new age process being much more inter and multidisciplinary like in PDP, practically the whole process can be considered to be a continued phase of prototyping. Anything that is interactive, collaborative and helps in communicating, testing and validation of ideas and sorting out potential problems during product evolution can be considered to be a prototype.

Prototype can be defined as the approximation of the product along a single dimension.[20] Any product consists of multiple features, which can be considered as dimensions along which the product performance can be measured. In the initial phases of development it can be single feature or aspect that needs to tested eg, the aesthetics, ergonomics of particular interface or mechanism but as design progresses a system can be termed to the dimension along which approximation is done [34]. It depends on what is being validated or tested and what problems need to be identified or solved.

In some sense a prototype can also be said to be the first one on which the rest are build on.[20] But quite commonly there are many versions build hence this definition holds true only in limited scenarios as anything between the Idea and Final product can classified as a prototype. It can be the first representation of the idea, but since the subsequent version can be refinement of the same it is bit hard to follow on this line of thought.

From the perspective of the organisation or the development team prototype can be considered to be something that brings together the knowledge for continuation of the development process. It can be considered to be a platform to test if the ideas generate any new knowledge that can help make a better product.

The following sections tries to explain the specific reasons to use any particular kind of prototypes and also the way to build and test them. The types of prototypes and the use of them as per their suitability for different stages of the product development cycle is also discussed. As noted previously, the scope has been limited to the rationale and the logical thought process in prototyping and doesn't include the techniques of prototyping.

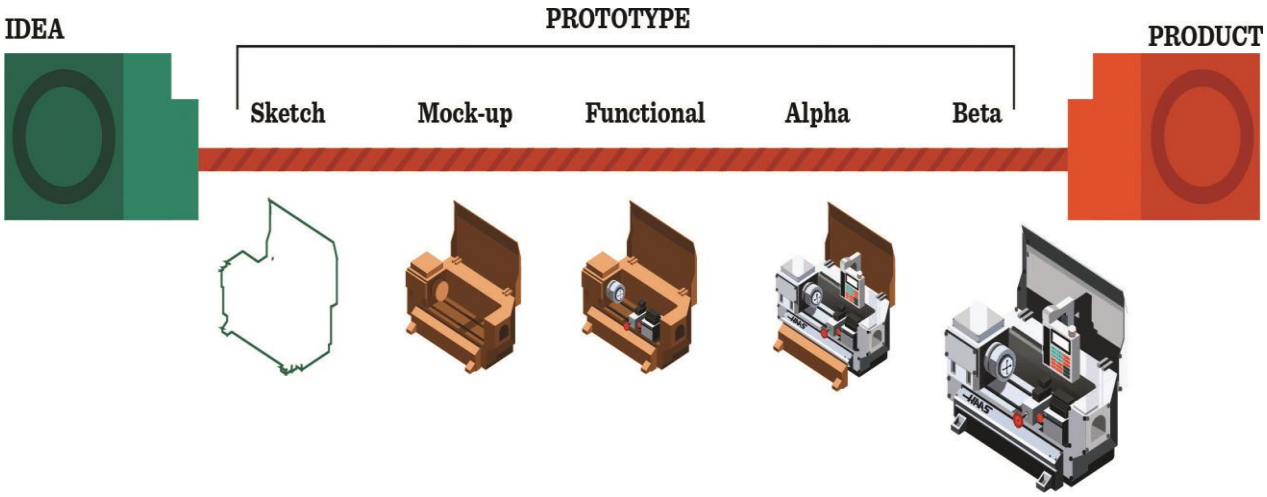


Figure 3.1: Different stages and types of prototypes

3.2. Why to prototype

Depending on stage of the process and purpose different kind of prototypes are used. Defining and analysing the problem to be addressed is the first step in the process. Any idea that addresses the problem is a thought and the product is its physical manifestation. For this conversion to happen effectively it is necessary to refine the idea so that it aligns with the parameters and specifications set for the product. Apart from communication within the team members the prototype can also help communication with external vendors or external consultants for other reasons.

The following section explains three main functions of prototypes[23]

3.2.1. Verification

The concept generation for any product begins with Ideation. Ideation process can vary greatly depending on the time and resources available as also on the policies and processes intrinsic to the organisation. Considering the large number of ideas generated at this level it is quite obvious for them to be evaluated based on parameter matrix. The matrix normally uses desirability, viability and feasibility as the core guidelines with varying degree of importance depending on the project needs. Not all of these ideas can be pursued in the development process from the resources point of view and also for reasons of practicality [21].

To make the process more efficient and effective the ideas being pursued should be verified so that they fit in the ecosystem and match the parameters set. The development project at hand can consist of many interconnected components and system which can affect each other and hence have an effect on the final product in multiple ways. The obvious factors can be thought out and their effect figured on thinking level but for larger eco-systems of development and operation it is almost impossible to figure out the success criterion. To see those effects and study the different options, prototypes are highly useful[13]. The

functioning of the idea can be based on number of assumptions but when prototyped these assumptions need to be put into practice exposing the virtues and vulnerabilities, which go, overlooked in the thought process [32][7]. Developers at times can base some of the ideas on passive experience but since prototyping is an active experience it can showcase exactly to what degree are those experience valid. Ideas can also be based on prior knowledge which could have been gained in different perspective, prototyping involves applying the prior knowledge in context of the project at hand thus validating the idea.

Specifications and needs criterion, for the product are based on user research providing the key insights and understandings. Since ethnographic studies can reveal gaps which can be critical for a product's success it important to understand them in equal importance [a]. At this stage prototyping can be fast and quick to keep costs low. Rough prototypes that are good enough to understand the needs are fine at this stage. This is facilitated by the fact that physical things evoke an response and based on the interaction rather than words which depends on their understanding.[33][23]

Any design team can come up with a variation of ideas, which are largely influenced, by their previous experiences and knowledge. These influences can at times lead to a possible commitment to a concept, which is flawed by overlooking its shortcomings. Prototyping helps in understanding the shortcoming and prevents a premature commitment to an idea which can prove costly as the process progresses [33][30]. The aim of this stage should be to fail early and quickly at this stage to try the next concept for verification by means of quick prototyping.

A quick iterative prototyping at this stage will help in verifying the practicalities of the implementing the idea [14]. This does not mean that you can envision all the problems you might encounter or guarantee a trouble free development, but giving a clear indication of which idea fits the parameters and also potential problems that might need to be resolved in

the process. This knowledge helps in choosing the right direction of development, which is efficient and has higher chance of success [28].

3.2.2. Refinement

Post verification the actual product development process with a committed concept under consideration. Solving one issue at a time, the prototyping undergoes refinements towards a final shaping of the product. Refinements are a multistage continuous process

To make the concept into successful product it needs to incorporate a large amount of details on both the consumer side as well as the organisational side. Prototypes make things easier as they are physical manifestation of those ideas and refinements[c].

An iterative process enhances the refinement. With ability to physically and mentally manipulate the prototypes the designers have the ability to test their ideas and their implementation. Also with the process being iterative in nature the improvement can be exponential[33]. At very iteration as one issue gets resolved, there is a chance a new issue might have been created. A refinement in prototype with every increment will resolves these minor conflicts in the product [13] [14].

All the details of the products are interconnected and at time also sequential in their implementation hence it's practically impossible to implement them all at once.A product with all its integration of different components, their details and the interaction amongst them, all of these cannot be thought of . It is only after studying these interactions that lead to addition or subtraction of features to make the functioning of the product better aligned with goals set [e].

All products are build up either from scratch or brand new ideas. Some products can be newer, better versions of existing ones. The improvement can only be made possible by trying out new idea on these before putting them into service. This is possible only through prototyping.[b][33]

The evolution of an idea towards the product is made efficient and effective through prototyping. This happens as a result of the continuous loop of ideate, test, analyse and implement. This cycle results in feature that are positive and favourable for the product thus leading to refinement at each stage. The end result being a more polished prototype closer to the end product at every iteration..

3.2.3. Communication

The disciplines of Engineering, Design and Business need to work seamlessly while bringing together the best attributes of each and merging them into one product. Each of these faculties can have a different understanding of the problem. These results in varying perspectives so as to what solution would be best to solve it. To have a consensus on the problem and the solution, a common understanding of the idea needs to be developed. An effective communication is one of the key cornerstones of a successful product development [b]

Most common form of communication is verbal description of ideas and thoughts. However the same words could be understood very differently by different people. There are number of reasons for these confusions – like, different academic backgrounds, prior experiences and such. This difference in understanding can lead to potentially large problems later on as the different aspects are integrated. Since prototype is something that is not only visual but also can be interacted with physically it helps in developing a common understanding [7]. Also the ability to manipulate and modify the prototype easily increases interaction and exchange of ideas[23][e]. This exchange of ideas has potential to bring all ideas together into a strong concept. This is aided by virtue of physical prototypes being better at explaining the concept than other medium of expressions of the idea. Hence with a visual and a tactile prototype there is not much scope to make wrong assumptions that might misdirect the development. Irrespective of the resolution and fidelity, a prototype has much higher clarity than any description of an idea. Prototypes removes the barrier of imagination and understanding between the different participant of the development process [a][33][22].

A product needs to be aligned closely with the needs of the user. For that purpose it is necessary to get the user opinion and inputs on the ideas. A verbal description can be many times, difficult to understand and leaves a lot of scope of interpretation of what is being described to both the client as well as the developer. This can cause a misunderstanding of

what is being told which can result in a solution that doesn't match with the needs of the consumer. A prototype helps in more precise and accurate expression of the needs and feelings on the user side. A prototype, which can be interacted with, evokes a response, which represents the true feeling regarding the idea. This reduces the chance of product failure due to wrongful understanding of needs. In the case of core consumer products this technique can be used for developing the product along with the consumer. This co-creation might be a bit lengthy process but the product is very closely aligned to user needs[a] Thus prototyping is not only technique and skill of building but also an effective and important means of communication. A way of sharing knowledge

3.3. Prototype- The Variety

The previous two sections define the prototype and then explain the main three ways in which it contributes to the process. It is not one size fit all approach. There are different types of prototype which work differently in different stages of the process even though performing the same function. Following sections describe the different types of prototypes and how they affect the development process.

3.3.1. Sketching

Product development process begins with an Idea based on the objectives that have to be achieved. Sketching or doodling is among the easiest and quite often the best way to express an idea. Sketching is an intuitive tool, that most people are familiar with to express a product thought. A sketch is extremely dynamic media to collaborate and a good team working tool as it can be added upon or modified on the go while working together.

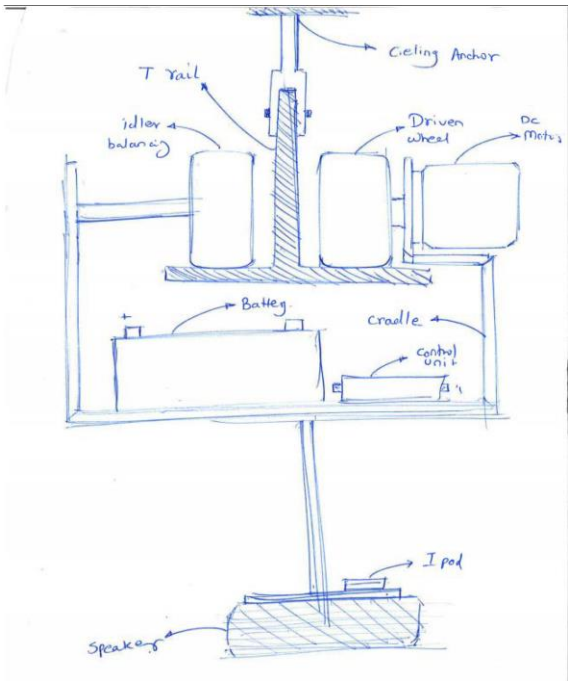
In early stage of development, the details are scarce and hence most of the sketches are general and not discipline specific. Since such visual work has very uniform understanding it develops a platform of common knowledge, which accelerates the development process [19]. Sketches are unlikely to gain affinity since they are low in investment of efforts and hence provide lesser resistance to discard in the interest of newer ideas.

Regarding the technique and skill of sketching, the aim is not to create a work of art but use it as a basic prototyping tool to express thoughts. When the idea is in explorative stage the quality of sketching is not that important but the effectiveness of it to expresses the idea in way that others involved understand it or not is. Since it is not skill but a medium of expression, the outcome or what it can accomplish is only limited by the imagination of the

sketcher[2]. This also aids in discovering aspects, which might go unnoticed in a normal discussion

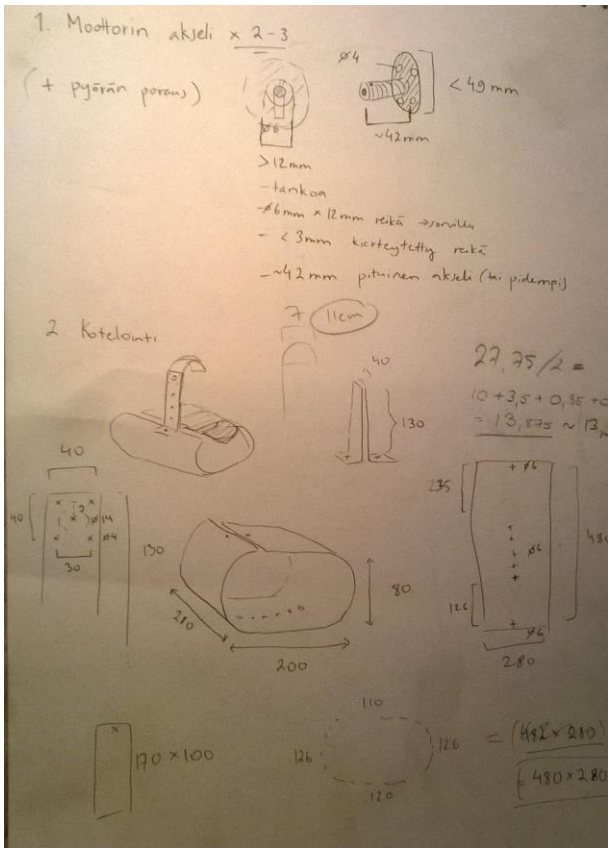
Inherently a sketch is fast and easy to manipulate as the idea grows, so it aids in getting a quick judgement on the feature being discussed. Sketching being exploratory in nature it encourages to evaluate alternative ideas, this helps in avoiding design fixation prematurely. Working with this kind of explorative approach helps in making fast but better informed decisions [3][33]

All the points stated above not only validate the use of sketch as prototype but they also encourage its use in product development context. There are certain aspects related to sketching to be kept in mind to make it an effective prototype. It is important to use sketching as medium of expression of the idea rather than a skill. The quality of the sketch doesn't matter but what it delivers does. A faster and more creative result is obtained by the use of quick, thinking sketches rather than polished sketches normally used for presentations and documentation[2]. With use of sketches there is better understanding irrespective of the language and work background and this helps in having a common perspective of things being discussed. A good resolved sketch is often the foundation to commit to more invested approaches of prototyping.



A student project to design and manufacture a suspended monorail system for an art gallery. The sketch was used to verify the feasibility of the concept and communicate the team's idea to the artists for approval

Figure:3.1 Sketch of concept of a mechatronic system



After the approval from the artist, the next sketches for system level design were made. These sketches were used to refine the concept and also finalising the form factor as well as some of the technical parameters

Figure3.2: Sketch used to figure out component specifications

3.3.2. Low-Resolution

This is the first step of physical prototyping. A commonly used term for these prototypes is 'Quick and Dirty' since they are fast to make but lack the precision and clean outlook normally associated with prototypes. Quick and dirty prototype is evolution of the sketches into their physical interpretation. The materials and tools used for this type of prototyping are simple, cheap and easily manipulated. It is essential to begin with as few components and attributes as possible as simple things are easily understood and help in verifying thoughts and clarifying idea at the rough end[1]. Rough prototypes are generally devoid of details. Prototyping in this way is quite important as in the early stages of development it is necessary to have the clear idea verified [e][7] Details can distract from the core idea and divert attention from the critical aspects of the product thus reducing the value of the effort. During the early stages of development the system is segmented, making it possible for all the aspects to be explored and analysed. It provides the necessary knowledge to make decisions regarding the future of the development process.

With faster build times and subsequent testing this stage is highly iterative. The focus is on quantity over quality as with each iteration the number of undesirable and redundant features reduces [33]. The number of iteration is dependent on multiple factors. There is no set rule on how many cycles of iterations will lead to a good result [21]. This is phase of quick builds and refining them with tests, rather than building big, complex and detailed prototypes[e]. Academic studies have proved that a prototype that is built fast and then debugged with appropriate testing results in a better concept for the final product [3] [29].

Prototyping effort at this stage should concentrate on the concept and not the details. Thinking about the detail at such early stages can have bad consequences later as concentrating on details can lead compromise of the concept. [13][27]. The materials used and the fabrication methods employed are prime indicators of how many iterations can be

achieved as these are the factors which affect the fidelity and time required for each iteration[21]. Apart from materials and fabrication methods, experience and skill of the team can also influence the number of iterations, as do the time and other resources available for the development process.

The precision and details of the concept are not known at this point hence it is necessary to understand the physical phenomenon of the crafting technique. Lack of this knowledge can lead to incorrect understanding of the idea or wrong assumptions being made be while testing [33]. The reason for misunderstanding is that since materials and techniques are quite rudimentary the outcome is an approximate representation of the idea under development. This approximation necessitates use of considerable imagination on part of the team members to realise the real idea being delivered by the prototype. Important decisions relating to the product's development can taken easily with the necessary knowledge obtained during this prototyping and testing phase[b].

There can be cases where the system under development might consist of two or more complementary but equally important attributes like in mechatronics (Mechanical and Electronics) . It is vital that both the attributes are prototyped independently but the teams always discuss the core interaction points of both. Integration of the whole system becomes much simpler and less troublesome task later on if the interaction points are well configured. [d]. The process at this stage again is not much about skill of making polished prototypes but more about expressing and verifying the ideas within the team and various stakeholders. The lack of requirement of building skill makes it easy to execute it in multidisciplinary teams. This unravels potential overlapping problems resulting in more coherent development. Also the abstract nature of the prototypes gives a better understanding of usability issues [a].b All these factors make quick and dirty prototypes indispensable to product development.

The famous case of the surgical Tool design by Ideo. The objects available on the table a marker, tape, clip and small plastic case were used to quickly prototype the form of the tool. The prototype was used to communicate the idea to the client and get it verified

Figure3.4: Low-resolution prototype

A student project involving wearable technology. To test the placement of the camera a quick harness was made with a glove and some elastic bands. The prototype was used to test the effect on functionality when was camera fixed to back of the palm.

Figure3.5: Low-resolution prototype

3.3.3. Mock-ups

The mock-ups prototypes are good way of making decisions regarding the concepts and directions to be chosen in which the development process will follow. These are still mostly non-functional prototypes. They closely approximate the look and feel of the product [35]. These prototypes can still be paper or cardboard prototypes but of higher resolution and fidelity. The techniques used in fabrication are more precise than quick and dirty ones. At this stage the idea is bit more refined and less of an approximation and the fabrication time in most cases is less than in quick and dirty stage. Knowledge gained from, the previous prototyping exercise guide onto exactly what and how to build. Previous prototypes help by acting as a base to add the refinements upon them. These prototypes being of higher fidelity and resolution in many cases they can be used for actual user testing.[a][13] These predominantly test interaction and experience of the product. Important point is to keep things a bit abstract as they can distract the user from the core of the idea. Product mock ups are devoid of issues pertaining to feasibility and viability as it is not fully known how that might affect the final product specifications.

On technical front Mock ups are useful on figuring out potential issues pertaining to technical feasibility as well as the production issues. Also non functional systems give an insight into the assembly and overall layout of the components which might affect the final appearance of the product. In this aspect they are a good tool for development process by multidisciplinary team[a][b][d][e] . They can be an evolution of the quick and dirty versions made earlier or use them as starting point. Process is to build on the iterations showing the progress and evolution of the product idea. Mock-ups are also sometimes used as early manifestations of industrial design trends in the product development. They help in setting up the specifications of the product under development so as to build prototypes with more functionality and details [35].

A PdP project where a solution for Elevators for under construction buildings was explored. A high resolution non-functional mock-up was to communicate the idea to the sponsors and used in an exhibition

Figure 3.6 : High resolution mock-up

A high resolution mock up used to communicate idea

Figure 3.7 : High resolution mock-up for communication

Figure 3.8: Low resolution mock-up for testing

A low-resolution mock-up of new concept for on board storage in passenger planes. The prototype made from readily available materials was used to demonstrate and gauge user response to the idea

3.3.4. Functional

The functional mock ups help in decision making regarding concepts in early stages and can even point out some potential problems relating to them. Various aspects of user interaction can be explored at this stage but it can still require quite a bit of imagination, role play and simulation . All the previous prototyping exercises guide towards getting a refined picture of the functional needs of the product. Even though the functions are a critical aspect in the user experience, for purpose of testing they can be demonstrated by use of simulation and role-play. The testing can be done while keeping the engineering aspects of the product to the minimum. Although engineering is critical to achieve the desired functionality of the product, it is aspect of the product with which the user interaction is limited. The result of engineering with which the customers interact is the functionality of the product and that determines the experience.

Predominantly at this stage the engineering aspects of the product can be said to be either of mechanical or electronics. The main principle of fabricating a functional prototype is to concentrate on the key function [b] [c]. The technical properties of these prototypes can be very different from what the final product is envisioned to have. Main focus of these prototypes is to demonstrate and test the functionality product should posses. The materials, fabrication techniques and other physical properties are generally decided on resources available for this stage of prototyping. In modern engineering processes it is quite common to design and refine mechanicals using computer aided engineering (C.A.E). This can also be considered to prototype as they help in generating the knowledge necessary to take decisions regarding product attributes. The physical prototyping in this case is carried at much later stage of the process when the most of the details are known and the concept has been verified and found satisfactory to the objectives it supposed to be meet. These prototypes have a very high resolution and fidelity. Though this can be resource efficient, it can affect the overall

thoughtfulness of the concept design as it requires focus on details [27], specifically so if carried out too early in the process [26]

This stage of development generally leads to a detailed set of specifications for the process to continue.

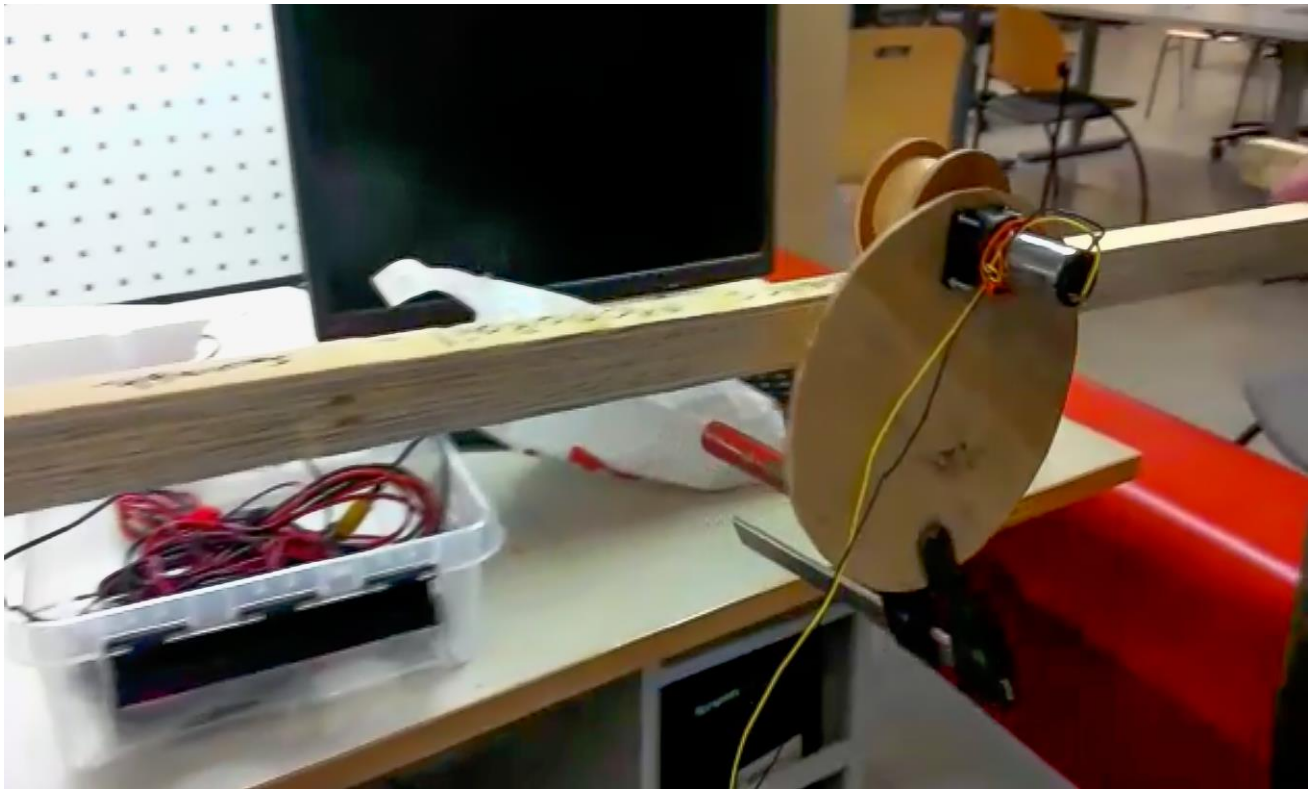


Figure 3.9: Functional system

The functional prototype of monorail system for an art gallery. The aim of the prototype was to test motor control systems and dynamic balance of the system in motion. The load carriage not yet designed the weight was simulated by use of a C clamp.

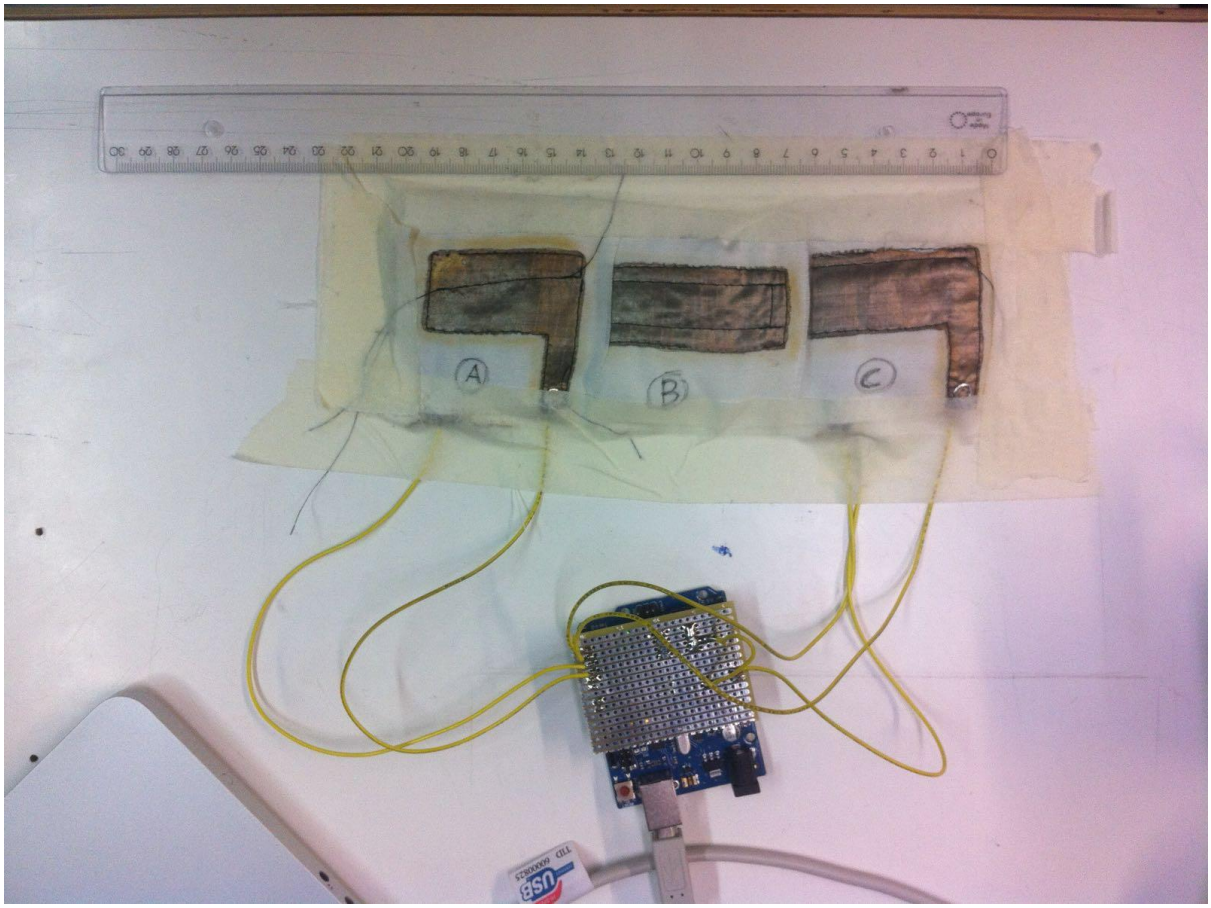


Figure 3.10: Functional system

A functional prototype touch sensitive fabric. The prototype was used to test the sensors for the fabric toys for children. The purpose was testing the functionality of the sensors, the control systems were off the shelf and not optimised for the system being designed.
Photo credits: Lisa Gerkens

3.3.5. Alpha

These are the prototypes, which closely match the final specifications of the product under development. After finalising the specifications in the earlier stages these match in resolution and fidelity to final product. They are also made from the same materials and with same physical properties as of the final. The biggest difference is that production methods and the craftsmanship used are more suitable for the making one-off or small numbers. This stage is mostly about troubleshooting and fine-tuning the features if necessary. At this stage all the specifications are set and even the finer details are incorporated in the prototypes. These are very high resolution and high fidelity prototypes also give an idea of any potential problems in serial manufacturing, which might have been overlooked or not understood in the process so far

3.3.6. Beta

These are final prototypes also called as pre-production versions. These are not only made with the actual material and have real physical attributes but also use the same manufacturing processes as the final product. These are predominantly a test bed for the manufacturing and the logistic system. This fine-tunes the manufacturing activities for serial production to commence. Also as these are as close to the real product as possible, these are quite often given to real user to be tested under actual operational conditions. This is like the last safety check to see that the product performs and meets the parameters it was designed for. As all the aspects are very close to reality this is good test of the reliability and overall performance.

4. Prototypes- the Applications

On a functional level the prototypes help the process in decision-making. The way they do that is by assisting in determining the architectural interface, the aesthetics, the feasibility of the product.

The concentration of this thesis is on manufactured products. In this regard the prototypes can be split in two broad categories namely Engineering and Design. Either one or both of these can help in fulfilling the different purposes prototypes are used for. The way this is achieved is by determining the architectural interface, feasibility or communication of the project at hand. [20][34]

4.1. Engineering

As the term suggests these prototypes explore the technical aspects of the product. The technicalities are not only limited to the structure and functioning of the product but also the practicalities like manufacturing and logistics involved. These can be of 2 basic types Mechanical and Electronics. There can be a further classification but as concentration is on early stage prototypes, when details are scarce keeping things simple and broad is better for subsequent stages.

4.1.1. Mechanical

These prototypes range from mechanics of the system to the understanding the manufacturing issues. In the early stages the concentration is mostly on verifying and evaluating different concepts, and refining those chosen for further development.

For mechanical systems it's always better to start with sketching the different components. Sketching is a fast way to figure out the relative placement of components and also their interaction. Making sketches with dimensions gives them more definition but still maintain the flexibility to modify concept as the finer details are still unknown[33]. CAD models can be used to stimulate the mechanism to find the finer aspects of the interaction of different components [b]. It should also be kept in mind that use of CAD doesn't compromise the core of the concept. Since CAD requires certain amount of details for it to work, it can divert the thinking from the core of the concept which crucial at this stage.[27]

The prototype should be key function oriented. The objective should be to test, demonstrate and evaluate the function rather than just fulfilling it. The process should begin with a simple prototype and as few components as possible. Most of the materials used are easily manipulated with simple hand tools. Unless the properties of material are important eg thermal conductivity then only real materials could be used. The use of simple materials like cardboard, foamboard or wood which are easy to manipulate is recommended since fabrication is faster. Additionally these not being actual production materials do not constrain the imagination. This sense of abstractness helps in greater exploration of the different aspects of the concept. Encouraging evolutionary iteration, adding on the already existing one to make the next version is crucial. This makes it easy to iterate and add details with increase in knowledge. The iterative process gives a security against failure. The last prototype version up to which the things worked is always there as a reference. So in case of failure at any point downstream in the process, it's not a beginning from scratch but jallows

you to retrace to the point up to which the things worked[33]. Being an evolutionary process the time required for subsequent iteration reduces with increase in knowledge and pre existing prototypes acting as base to build upon.[21]

Even if the idea is in nascent stage and the techniques used are rudimentary, these prototypes still give a valuable insight into potential issues involved in manufacturing. Manufacturing techniques for the product under development should always be kept in mind. The knowledge of physical phenomenon behind the rudimentary fabrication is vital to keep manufacturing in perspective.. Lack of this knowledge can lead to decisions, which might prove infeasible as more details aspects of the product emerge. Since at this stage all the subsystems are prototyped individually their interaction should always be in the discussion so that integrating them in the later stage become straightforward and trouble free.[d]

If possible the fabrication team for the prototype should be different than design team. This encourages interaction and gets a different perspective which can lead uncovering of aspects and properties the design team might have overlooked.[b]

Testing of these prototypes depends on the state of the prototype and the features being evaluated. Mechanical prototypes as they evolve their properties start to closely to those of the final product. This enhances capabilities/ functionalities enabling them to test even the minute details of product. This increase in resolution and fidelity not only evaluates features but also the interaction between different features.

While testing as the features and functions are approximate representation of the final product ,it may require quite a bit of imagination. It might be assumed that the tester has the same sort of logic and imagination as the designer and understands the concept in the same way which might not be the case. This should be kept in mind while analysing the feedback from the test. The feedback from the test should be analysed and should not be taken literally. It should be clarified with a further discussion with the tester if necessary.[33][b] The assumptions

made during the design and fabrication of the prototype should be taken in consideration while analysing the feedback and developing the next iteration

For mechanical tests, which are independent of the user, the key function should be the cornerstone around which the test is planned, executed and analysed. These being the technical aspects of the product they might require use of real materials and techniques. This makes them resource intensive. In some cases a computer simulation can give the required information so as to continue the development further

4.1.2. Electronics

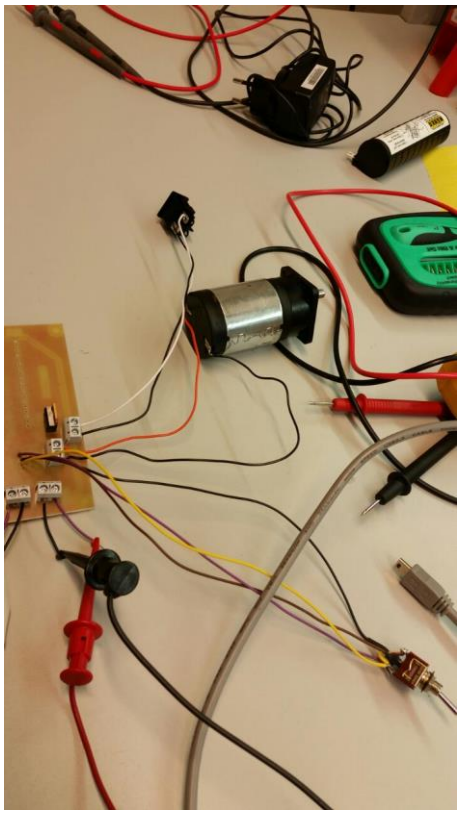
Electronics are the control and actuator systems of a product. In the very early stages of development when idea is to be evaluated it's very easy to prototype the system. Since at that point only the functionalities need to be demonstrated electronics, proof of concepts can be done by simple mechanics and roleplay. As the concept advances and more details come into the picture then the actual system design can be thought about.

The components in electronics and associated task like control software code may need specific training. This makes prototyping electronics much more skill oriented and also resource intensive activity. It is a good practice to discuss the idea, concept plan with experts to clarify any doubts before had, it helps save time by reducing the need of troubleshooting and selecting the right components. It is important to do some benchmarking in terms of the objectives you are trying to cater to with the systems. This can give some knowledge regarding the relevance of the idea and if anything similar exists. This can lead to usage of components of the shelf saving time. [c]

It is beneficial to have the know how of the tools and devices to be used for the prototyping exercise. For simple systems with a few components a breadboard prototype can work and also be iterated quite easily. As the system goes bigger the number of components increases and that makes the prototype more complex. In such cases it is useful to make circuit boards rather than breadboards as in case of it is easy to locate the flaw and rectify. Also plan for the next iteration becomes easier. This is dependent on availability of the resources of the requisite functionality. Its always a balance between time, resources available and the resolution that can be achieved and is needed.[c]

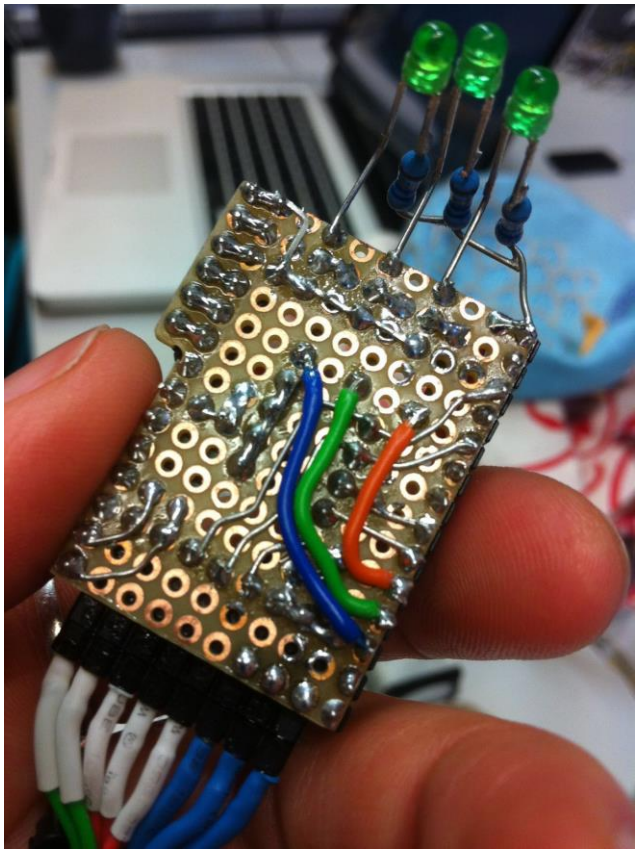
It is possible to get to full resolution and high fidelity prototypes after four iterations. Like in mechanical prototypes these should also be key function oriented. These functions become the cornerstone around which the whole system is designed. There could be number of

modules present in the system which need to work seamlessly to achieve the functionality necessary of the system. Even though the modules are designed separately, their integration should be always be considered during the design process. The technical parameters like power rating should be double checked and made sure that all the components have parameters compatible with one another[d]. Since the functionality is based heavily on the components used, the budgetary constraints should be kept in mind as they can be the deciding factor, if the system should be developed or other alternatives should be explored. These predominantly being technical side, the side with which the user interaction is very less the testing is quite easy and straightforward. The test protocols are quite well established and easy to follow, though might require specialised equipment.



A simple prototype used to test control circuit of DC motor. To make changes if necessary the components were screwed on rather than solder on

Figure 4.1: Quick Electronics prototype



A prototype where the components are soldered on proto board. These are more refined and higher in resolution
Photo credit: Lisa Gerkens

Figure 4.2: Proto-board prototype

4.2. Design

These are prototypes that predominantly deal with the aesthetics and the usability of the product. It is human side of the product. These are the prototypes that deal with the experience of using the product. Design prototypes can come in handy even before the actual solution development starts. Skilful use of prototypes can help in figuring out the actual problem that is being dealt with. Identifying the right problem in case of human factors of a product is close to being halfway through the solution. The prototypes used for user interaction are the rough ones devoid of much details, just boiled down to their very essence of the idea. This is crucial as details and unnecessary accessories can distract users leading to an experience and reaction that might be misleading from the actual problem [a]. User interaction necessitates the prototype to be easily modified as this is much more exploratory in nature than engineering development. Also this involves the actual users whose skill and experience of such kind of work can be limited [22].

Like engineering prototypes this also need to be fabricated from the point of view of test. What is it that needs to found, is it the experience of usage or reaction to the aesthetics is what should guide design and fabrication of the prototype. The product can have different scenarios and aspects related to its usage, while testing it should be tried to explore as many of them as possible . This exploration enables figuring out not only varied problems and aspects but also their interconnection which at times is not obvious [a].

To test the idea it is important to create the experience related usage of the product. The parameters and functions critical for creating the experience of the using the product should be implemented while all other details can be left out. During this early stage of development the things should be kept abstract and the instructions for the tester should be as few as possible. This encourages the testing audience to be more exploratory leading to greater

insights for the design team. Important point at this stage is to keep in mind that it's just an idea and its approximation and hence the feedback cannot be taken literally but should be analysed [12]. Quite often the tester cannot share why a certain feature works or not for them, in such scenarios some exploration into their tests and feedback can prove beneficial to refine the product. With the progress of the process and as the resolution of prototypes increase the test can be made more precise to deal with particular aspects of the product. These test can be done with clever and smart use of simulations so at times even non availability of the real product doesn't hamper the test [a][b][25].

The experience of the product is not only limited to the aesthetics and the thoughtfulness of the functions but also the technical aspects necessary to achieve the functionality . The technical factors like the vibrations, temperature etc can affect the experience as well. Even though they are supporting the functions from and the user interactions with them are minimal they can dictate the response to the product. In this scenario the engineering prototypes are used for testing and hence they should be adapted for this purpose. This adaptation should be considered while analysing the result as it might affect the perception and the feedback. Design prototypes can be easiest to make but the logic behind them can be hardest to figure out making the overall effort the highest of all prototyping activities.

5. Study on effects of prototypes

To showcase the benefits of prototype intensive process a small PD6 workshop was conducted which is discussed below:

5.1. PD6

PD6-Product development in 6 hours. It is a workshop used frequently for teaching methodologies in different project based courses at Design Factory. The student teams are given a problem brief and they have to undertake the whole product development process in 6 hours and present the final outcome as a prototype.The workshop is designed such that it encourages building prototypes. There is planned schedule and a check is kept on the team's progress. The time pressure and the whole dynamic nature of the situation forces the team to think and act fast. It encourages quick decisions and execution. Philosophy behind the whole exercise is to fail early in order to succeed sooner. The resolution and fidelity of the resulting prototypes is quite low but it enables the students to grasp the whole idea of the solution and take the project forward. A facilitator keeps a check on the progress and guides if and only when necessary.

5.2. Experiment

To gauge the effect of intensive prototyping on product process an experiment was conducted. The experiment was conducted in form of a PD6 workshop with participants being first year master's students of Industrial Design Business Management (IDBM). The students represent design, engineering and business at bachelors level and they were formed into teams randomly. The students had attended workshop on sketching and model making so as to get the basic knowledge on the practicalities of the prototyping process. Idea was to see for same kind of product if one group used a process which was intensive on prototyping while other was free to use a process of their choice. The experimental group students were asked to try and base all their decisions regarding the products evolution on prototypes, document them and submit them at end of the workshop. The end outcomes of both the experimental and control group were judged by panel of experts based on various parameters. Since the students were from engineering, business and design the problem statement should be something of relevance to all three and not prefer a certain discipline as this can affect the end result as it will an effect on the process being followed for development .

The problem chosen was: Demonstrate a new way of waking up a person on given time.

All the teams were provided with a booklet regarding with information about prototypes, It contained information on the functions, the types and some quick guidelines and principles on prototyping and testing.

An extra facilitator was provided to the teams in the experimental group to guide them through the process. It was not a case of active facilitation but more a source of extra knowledge in case they didn't understand the booklet or had doubts. Both the groups had basic facilitation and checkpoints to keep a track on their progress. All the teams for their end result came with a mobile application; the 2 teams in the experimental group had some hardware that interacted with the application to accomplish the task. At the final presentation

it was found that none of the team followed the iterative process of prototyping which is the norm in such workshops. It was also found that none of the participants had much experience or knowledge of quick and dirty prototyping which was expected, considering their background. It is also interesting to note that teams with higher number of students from business background engaged in some user study to determine user references. Contrastingly the designers and engineers came up with ideas based on facts and previous research on the given problem statement.

The evaluation was based on the final prototypes presented to a panel of judges which gave insights into the process and usefulness of the prototypes. The teams adjudged best in both experimental group as well as the control group had prototypes, which had high fidelity experience even though the prototypes were low resolutions. This showcases the effective usage of prototypes as a communication medium. The judges commented that it was fairly easy to understand the functionalities and the logic behind the idea and hence its effectiveness. Compared to them, other prototypes of similar resolution didn't have the same fidelity. Also as the feedback was based on the actual understanding of the idea, which could be interacted with, it can be safely said that the ideas were verified to be useful enough to continue the development process. As the teams just made one prototype each and didn't have any iteration it is difficult to comment on the refinement function from their prototyping process. Even though the teams did not follow the prototype intensive method of development, when asked, the reason behind the lack of the answers were as anticipated. They are lack of knowledge of techniques and hence outside the scope of this thesis since the concentration is on prototypes and their effects and usage. There is still lot of evidence on the usefulness of prototypes from the very early stage and using them as decision-making tool. Under the right circumstances the participant students also agreed to the productive effects of prototypes and also make them integral to their development process

6. Discussion and Future Work

A successful product development is always expected to be riddled with obstacles - some easy and straightforward to deal with while some others needing a lot of effort. Taking a solution or an idea to reality with all the constraints is the challenge.

Idea generation in most cases is not a problem and the study throws light on what techniques work best for ideation process. Most of these ways broadly categorised under Brainstorming/ body storming category. The challenge starts from, the multitude of ideas generated and ends at choosing the right ones for further development? The first step in that direction is validation of chosen ideas and then refining them. These steps can be made effective by use of prototypes and which is the main concentration point of the thesis is about.

On the engineering side of development it has become the norm to proceed with use of digital tool like CAD ,CAE and CAM. These have advantages and are indispensable in the advanced stages of development but in the early stages of the process they can be a bit restrictive. To make the digital systems work a certain amount of detail is necessary. Figuring out and finalising these details can take some time and effort which potentially compromises the concept by preventing exploration of all the factors and possibilities. This lack of idea expansion can lead to some problem in the advanced development and even potential failure of the product. Quick, rough prototypes help in understanding the not so obvious facets of the concept. These prototypes point out the features that require more attention when working on the details. This saves time and makes the digital design process much more efficient.

Success of the development process is heavily influenced by inter-team communication during the project, as it is a collaborative effort. This communication was clearly enhanced to a great extent by use of prototypes. A prototype acts as a facilitator as well as platform to share ideas and thoughts. In early stages since the prototypes are easily manipulated, they

encourage build up of ideas by improving the understanding between different team members.

The PD6 workshop and the academic literature supporting the benefits of prototyping in early stages, there were some issues that can prevented the teams from adopting a build intensive process. The amount of effort needed for a decent physical prototype can be quite high compared to a computer model. Result of prototyping can seem to be a bit underwhelming compared to the time and resources required. This can be even more true if teams lack understanding of building and testing using simple materials. In scenarios where resources are not a issue presenting a rough prototype can be bit embarrassing for the team. Quite commonly stakeholders don't know the process and don't understand the value of so called quick and dirty prototypes and may not appreciate or even ridicule the effort in effect reducing the willingness of the team to prototype. This was supported by the discussion with the students after the workshop.

The perception of prototype building has been something that requires more skills and hence for select few. In reality it is much more about sharing knowledge and communication of ideas. It is also misunderstood to be overwhelmingly complicated and time consuming rather than simple, cheap and easy task to accomplish. Yes it is a skill to build a good prototype but that factor counts in the advanced stages of development. In the early stages it's about the concept and not the details. The building techniques are simple and familiar but their understanding is necessary to make a good prototype. The thought process is important, which naturally leads to good execution. Concentration should be first on what needs to be found out/tested followed by how to do it rather than the other way round.

For the scope of the thesis the pedagogical aspect has been not discussed. It is important to understand how the learnings from prototyping happen to further develop the prototyping process to be more effective.

For larger acceptance of value of early stage prototyping a full empirical study could be useful. An attempt in this regard was made in the process of this thesis in form PD6 workshop. It wasn't conclusive due to multiple of factors. Even though teams were formed in random they were skewed with one group having majority of engineers and designers and other group with business students. It was assumed that the students had some kind of prior prototyping experience of some kind considering the courses they were doing, but later on a questionnaire revealed that most of the students were making such prototypes for the first time . They had little or no coaching on that aspect during their other courses. Whatever little prototyping activity they did points to the fact that the importance of prototyping is well accepted but clear guiding points to follow the process are missing.

It can be concluded that prototyping is bit of an undervalued and misinterpreted activity in product development process. It requires more work to refine and have an efficient strategy for early stages of development with all allied factors need to be studied carefully. But with right knowledge and understanding it in effect can make the development process shorter and more resource efficient with the quality of products getting better.

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Interviews

[a] Gerkens Lisa, Product Development lead and Co-Founder LeeLuu Labs

[b] Kaariainen Kari, Model Maker, Aalto Design Factory

[c] Leal David, Manager Electroshop, Aalto Design Factory

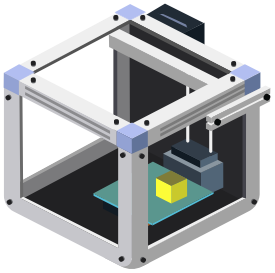
[d] Takala Marko, Electroshop Assistant, Aalto Design Factory

[e] Taanila Pyry, Industrial Designer and Co-Founder Catchbox

Appendix

Contents: Handbook of Prototyping- PD6 Workshop

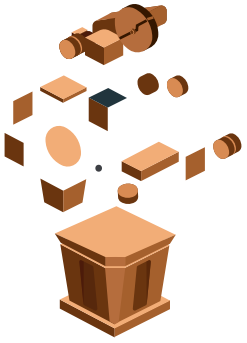
Handbook of Prototyping V1.0



Purpose of prototype:

Validate Idea: *Any product development starts with an idea. The idea can only be pursued if it fits the needs and parameters to be fulfilled. To validate the idea against these parameters prototypes are used*

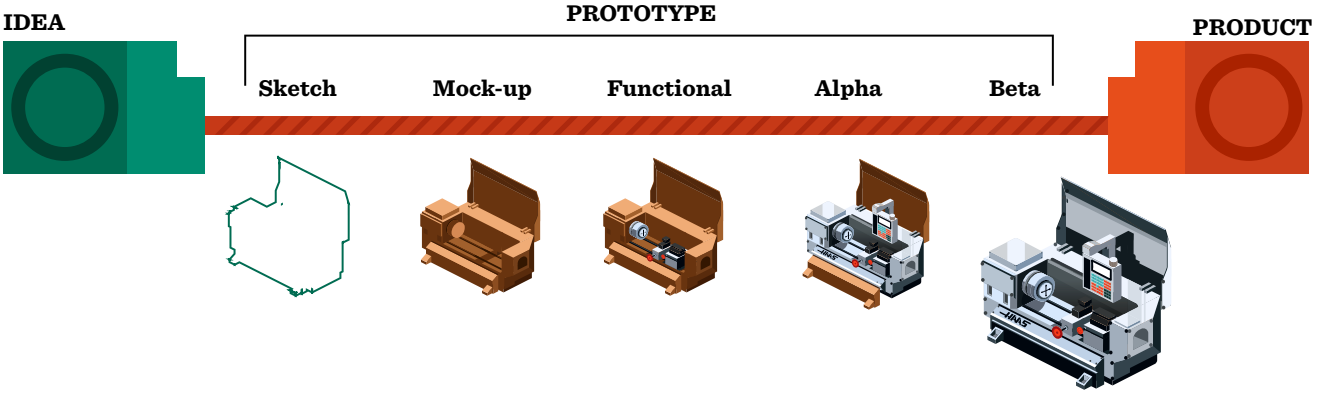
An idea is a thought and product is its physical implementation hence to evaluate that vimplementation prototypes are needed. To turn the idea into a concept it needs to be refined. This refinement is done to align the product with the needs it should fulfill . To test this prototypes are used as they are more efficient way of doing it



Prototype can be anything from a sketch to quick and dirty cardboard prototypes to the full beta versions. A physical interpretation which helps in taking the product idea forward can be considered to be a prototype.

It is approximation along a single dimension: *prototypes approximately represent or demonstrate one of the attributes/function of the final product. In the initial stages it can be a single attribute but as the process progresses it can be group of closely allied properties like subsystems.*

Prototype can also be considered the first model on which subsequent are build on. Aprototype is used to get all the knowledge together to continue the design/development process



All the phases between the idea and the final product can be considered to be a prototype.

Product Architecture : *A product is made up of different components, sub systems and modules. All of these interact with each other to fulfill the different requirements and perform the different functions of the product. A prototype can be used to test these interactions or the individual components themselves. The prototype should be developed with the key functions in mind. The supporting elements can be approximated in ways such that they don't affect the key functionality being tested.*

Feasibility: *A good product is developed in such a way that it can be manufactured efficiently. Any product is made from certain materials and will also contain one or more different technologies. It is necessary to figure out, if the resources available are competent enough to make the product to match the desired specification in stipulated time and cost. The resources include not only the materials but also the technologies available and the manufacturing process involved. This process can be a stage of compromise between the resources available and the specifications to be achived.*

Communication: *Most products are made by teams spread across different domains and disciplines. This requires that all the people involved have the same general understanding of what is being done. Sketches/illustrations like engineering drawings need some training and imagination to understand. A physical thing has general uniform understanding overall. To test the user experience it is critical that the concept is well understood. This is necessary to get a feedback that helps in aligning the process with the consumer.*

Prototypes can be roughly devided into two categories

Engineering:

These are the ones that handle the technical aspects of the product. As for now we are limiting our focus to manufactured products this category normally covers the mechanical and electronics aspect of the product. The logic and guiding principles behind both are the same but the process differs quite a lot.

Mechanical :

This prototype can be as simple as a sketch with rough dimensions . These prototypes normally follow evolving iterative process. The iterative process gives a security against total failure as there is always the earlier version to track up to the point where things worked. Testing these require quite a bit of imagination on part of the tester. As things can be approximated to concentrate on key function, the feedback needs to be carefully analysed. This also helps in determining the feasibility and viability of manufacturing

Electronics:

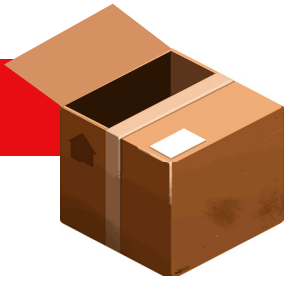
These are sort of straight to make and test but constrained by the technical feasibility and viability to match the needs. Instead of being an evolving iteration, each iteration can be a new prototype.

Design Prototypes:

These are the prototypes that explore the aesthetics as well as the user interaction and the experience of the product. They can range from product renderings to mock ups that deliver the experience. Like other prototypes they are also defined by the key function or the experience to be delivered. They are often non functional mockups so as to not influence user behaviour by unnecessary details.

WHY Function	HOW Type/Cateogry	WHAT Data Outcome
Architectural Interface	**Design** **Engineering**	**Appearence / Schematic** **Product atribute** **Objective Yes/no**
Feasibility	**Engineering**	**Objectives Yes/No** **Feature refinement**
Comunication	**Design**	**Customer Feedback** **Non Functional Mock up** **Appearance/ Schematic**

JUST DO IT ! *Fail early to succed faster...*



Guiding Principles of Prototyping.

- ***Build for testing,*** *build according how to test the objective at hand rather than how to fulfill the function.*
- ***Build to think*** *and think to build. Use Prototype as thinking tool.*
- ***Validating the idea*** *is important , refining and adding details is easy and can be done later.*
- ***Build the idea first*** *, optimization and details to be added as iterations progress.*
- ***Keep It simple****: Boil down the idea to the very basic essence and build accordingly.*
- *Start with as few components as possible and add gradually as idea builds.*
- ***Always iterate****, balance between time, resources and refinement needed determines the number of iterations to be done.*
- *When testing the experience keep the things abstract.*
- *Increase the precision of the test as the resolutions of prototype goes higher.*
- ***Analyse*** *the feedback, do not take it literally.*

Testing

- *Make a test Plan for the prototype*
- *Who is going to test and who is going to use the data.*
- *What is it that you are trying to find or validate.*
- *State the assumptions made to run the test.*
- *Document extensively. Documentation should cover all the aspects and variables, so as to give a result that takes process ahead in right direction.*
- *Analyse the data carefully.*

JUST DO IT!

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